"Rapid" Innovation: A Comparison of User and Manufacturer Innovations Through a Study of the Residential Construction Industry

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Abstract

Conventional wisdom suggests that builders of residential housing almost never innovate. In a study of the residential construction industry, I document quite a different picture: builders, rather than product and material manufacturers, are the developers of almost all of the innovations in a sample (n=34) researched in depth.

Measurement and comparison of economic incentives operating on builders versus manufacturers in this industry show how a pattern of builder innovation can make economic sense. Builders develop needs for innovations in the middle of construction work - and at that time the cost of delay is very high. Under these conditions builders find innovation to be cost-effective - and so do innovate.

"Rapid" Innovation: A Comparison of User and Manufacturer Innovations Through a Study of the Residential Construction Industry[1]

I.0: Introduction

The purpose of this research is to expand our theoretical and empirical understanding of "learning by doing" (Arrow, 1974) and "learning by using" (Rosenberg, 1982) in the innovation process. I examine innovation during the implementation stage of a technology by drawing from a detailed, comprehensive, field-based study of innovations in stressed-skin panels in the residential construction industry, in the tradition of Glasser and Strauss (1967), Strauss (1987), and Eisenhardt (1989).

There are many ways of examining this problem; the one that provides the most insights is the model of "user innovation". As von Hippel has shown convincingly, user innovation is of great importance in a wide variety of industries (von Hippel, 1988). However, existing research on this topic has focused almost exclusively on the subset of user innovations that are commercialized by manufacturers; the attributes and importance of user innovations that are not commercialized remain to be explored, and therefore our understanding of the full scope of innovation by users remains limited as well (Cainarca et al., 1989; Rogers, 1983). An objective of this research is to respond to this deficiency by identifying a full set of manufacturer and user innovations associated with a single technology, and to distinguish among the operative incentives and mechanisms for appropriating the benefits associated with the innovations.

Several preliminary studies and some anecdotal evidence imply that technological change often occurs during the application of a technology (Bell and Hill, 1978; Tietel, 1984; Rogers, 1983). In many cases, the problems that provoke these changes are expected by the people who employ the technologies, but the exact nature of these problems are only identifiable during actual use. While the original providers of the technology may be aware that needs arise during application, the recipients of the technology may be in a better position to both identify the exact nature of the needs, and to meet them through their own innovations.

Users create most of the innovations in this study; through detailed evidence, I show that the reasons for this are much more complex than previously understood. A key implication of this research is that in industries characterized by highly sophisticated users and by technologies that must be integrated "in real time", users are likely to be a rich source of innovations essential in connecting separate technologies into a whole operating unit.

[1] I would like to thank Eric von Hippel and Rebecca Henderson for their invaluable comments on this paper.

1.1: Related Literature

Traditional models of innovation assume that technological innovation originates either from the manufacturer or from research and development laboratories. Many models concentrate on the response of manufacturers to market demands through technological innovations (Myers and Marquis, 1969; Abernathy and Utterback, 1978; Mansfield, 1968; Kamien and Schwartz, 1975; Nasbeth and Ray, 1974; Rogers, 1969; Vernon, 1971). Other research on innovation analyzes the contribution of research and development conducted by government or university laboratories to the public good (Fusfeld, 1986: Brooks, 1981; Isenson, 1969; Jervis, 1978). These models fail, however, to consider alternative sources of innovation, or the actual stages of implementation of the new technologies after they are introduced.

As mentioned earlier, the model which provides the most insight into this problem is that of "user" innovation. As von Hippel (1988) has shown conclusively, "users" of innovations as well as manufacturers can be sources of innovation and can contribute significant product and process developments. His research examined specific technological developments within nine different industries and found that users innovated in all nine industries and were major sources of the technological innovations in over half of the industries. From this research, von Hippel concluded that the source of innovation can be predicted by which participant expects to appropriate the economic benefits from the innovation. The costs of innovating for comparable products were analyzed, and it appears that users innovate when the technology is easy to modify, specifically when the costs for the user to innovate are decreased (von Hippel and Finkelstein, 1979).

Other research builds upon von Hippel's work. Several studies have found that the degree of innovation by users does not depend upon their expertise in the particular field (Voss, 1985; Feld, 1990). The manufacturers were seen to increase the rate of user innovation through lowering associated costs and increasing the ease of accomplishing the changes; these user innovations could then effectively be incorporated by the manufacturers into future product developments (Feld, 1990; Habermeier, 1990). Finally, when given the opportunity, users continually innovated and constantly exchanged information about those innovations (Johnson and Brown, 1986; Leonard-Barton and Rogers, 1981).

These findings have been echoed in work by other scholars in different fields. "Re-invention" or the alteration of the technology by users was often identified during the adoption and implementation stages to fit local conditions (Rogers, 1983; Bell and Hill, 1978; Teitel, 1984). Indeed, when the choice of the technology and other activities by the recipient of technology transfer is explicitly considered, modifications by users were often essential in achieving a successful transfer (Teitel, 1984; Bradbury et al, 1978). These modifications can be seen as economically rational responses to existing conditions, such as market demand and uncertainty. While these studies expand our understanding of the frequency of innovation by the users, they often fail to examine aspects of the technology itself in providing incentives and opportunites for innovation.

New research reveals that users may "retrofit" a technology when multiple generations of a technology coexist and "the system integrator function is carried out directly by the user" (Cainarca et al., 1989). Cainarca and colleagues found that

the "users want solutions consistent with their knowledge base and organization, while suppliers lack user-specific information and might not generalize specific needs." In consequence, users generate their own solutions to bridge the gap between the promise of the new technology and the known operational characteristics of the old technology.

The constraints of these studies are related to the traditional models in innovation upon which they build, namely the focus on the manufacturers and the benefits they can appropriate from innovations. This approach perpetuates the view that user innovation may represent a "partly pathological response to market disequilibria" (Cainarca et al, 1989), that is, a failure on the part of manufacturers to meet existing market needs.

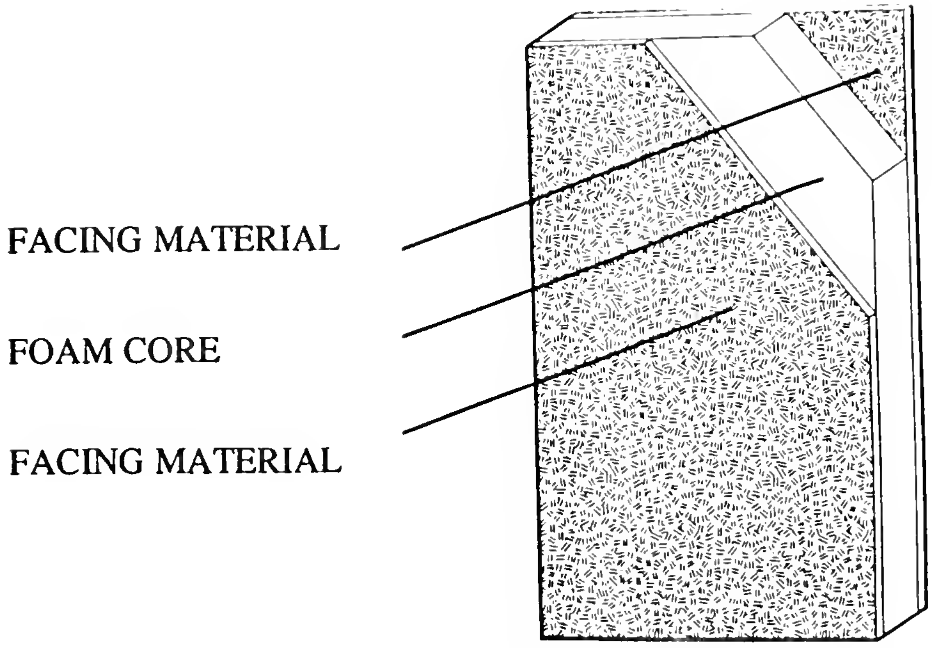
2.0: Study Sample and Methods

My empirical research is based on a detailed field study of a single major innovation in the construction of residential housing - the stressed-skin panel. These panels involve a major change in how houses are built. They involve distributing the load of a building over a continuous surface rather than concentrating it in discrete framing members. Adoption of this basic innovation requires the development of many related innovations having to do with accomodating the other elements needed in a house, such as roofing, flooring, and electrical systems to the new design constraints and freedoms associated with the use of stressed-skin panels.

The stressed-skin panel was first commercialized after World War II and has, I find, been improved by 34 separate innovations since that time. My narrow focus on this innovation and related improvements allows me to analyze exactly what occurs as an innovation is applied and progressively improved over time. Since the sample of innovations relating to the stressed-skin panels has occured relatively recently, I had the advantage of being able to find and interview participants in the various innovations who were, by and large, still working in the industry. The extent to which I can generalize my findings on the basis of this narrow sample is not clear, but I find no obvious sources of bias with respect to the issues I examine.

We may describe a stressed-skin panel as a "sandwich" of a solid core of plastic insulative foam laminated to the facing materials, where the facing materials or "skin" carry some portion of the building load. The panel acts similarly to an I-beam to distribute the load. Figure 1 shows the basic design of such a panel. The facing materials shown in the figure can be made of plywood, other structural wood sheets, gypsum board, or metal.

Figure 1: Basic design of a stressed-skin panel



In the course of my work I refer to innovations by "users" and by "manufacturers". An innovation can be classified in terms of its relationship to its creator, specifically how its creator appropriates the benefits. If the creator develops an innovation in order to use it, it is a "user innovation." It is a "manufacturer innovation" if the innovation is specifically developed to be manufactured and sold. This distinction is particularly useful in examining innovations which occur during the implementation of a technology, when either the "user" or the "manufacturer" may innovate, but each receives the benefits from the innovation through different mechanisms. In the instance of my study, a user is a builder of residential housing, and a manufacturer is a firm that manufacturers stressed-skin panels for commercial sale.

2.1: Sample of Innovations Related to Stressed-skin Panels

The sample for this research includes all the innovations that I was able to identify that have been actually used in construction to improve the basic stressed-skin panel. Each of these innovations has been widely adopted by builders in the industry. Some have also been manufactered for sale to builders by manufacturers who serve the housing industry. The sample contains 34 innovations, covering the entire time period of the use of the panels in residential construction, from 1970 to the present day. Table 1 lists these innovations, grouped by the function that they fulfill.

TABLE I: SAMPLE OF INNOVATIONS IN STRESSED-SKIN PANELS BY FUNCTION: FROM 1970-1990*

FUNCTION	N
Connection of panel to foundation	1
Connection of panel to frame	3
Connection of panel to roof	1
Structural connection between panels	2
Corner connection between panels	3
Insulated connection between panels	6
Framing of openings within panel	2
Installation of HVAC within panels in construction	2
Installation of wiring within panels in construction	7
Ventilation of roof within panels	2
Rendering panel insect repellent	4
Development of curved panels	1
TOTAL:	34

*1970 is the approximate beginning of the widespread use of the panels in residential construction.

SOURCE: Field interviews and panel installation manuals (see methodology).

The data gathered for each innovation consist of qualitative as well as selected quantitative information; they provide a rich description of the innovations associated with stressed-skin panels, including the conditions and incentives surrounding their creation.

2.2: DATA COLLECTION METHODS

I conducted interviews with all the major participants in the panel industry. These provided the core of my data for the sample of innovations to stressed-skin panels.[1] These interviews included the seven largest panel manufacturers, which equal over 80 percent of the market, and the seven largest builders who have consistently used stressed-skin panels for residential buildings and who have an average of 12 years experience with them. Although the large builders I interviewed account for only a small portion of the users of stressed-skin panels in residential construction (the residential construction industry is quite fragmented) their experience seems to me to be representative of the users in this field.

My interview data was supplemented by two other major sources: a survey questionnaire completed by over 100 builders who use stressed-skin panels; and interviews with experts in residential construction technologies and stressed-skin panels. Company technical and management documents, trade journals and technical publications provided further information on the innovations.

3.0: FINDINGS

The three major results of this study both confirm previous research findings and provide new insights. First, I find that residential builders were the primary sources of innovation, creating more than 80% of the innovations studied. The builders created these innovations only for use in their own building projects, and so I term them user innovations.

Second, I find that innovations developed by builders differed from those created by manufacturers. The former often involve physical connections between panel and non-panel building elements, while the manufacturers' innovations were limited to the single component of the stressed-skin panels. Third, I find that manufacturers commercialized only a small portion of all builder innovations, and they did not commercialize innovations pertaining to the connections among systems. In the remainder of this section I will develop and examine each of these major findings in turn.

3.1: USERS ARE THE LARGEST SOURCE OF INNOVATIONS

After a detailed study of my sample of thirty four innovations related to stressed-skin panels, I found that 82 percent had been developed by individual residential builders, and 18 percent by manufacturers of stressed-skin panels (Table 2). [2]

TABLE 2: INNOVATIONS IN STRESSED-SKIN PANELS BY FUNCTION AND SOURCE OF INNOVATION

	SOURCE OF INNOVS		
FUNCTION	USER	MFR	N
Connection of panel to foundation	1		1
Connection of panel to frame	3		3
Connection of panel to roof	1		1
Structural connect between panels	2		2
Corner connect between panels	1	2	3
Insulated connect between panels	3	3	6
Framing of openings within panel	1	1	2
Installation of HVAC within panels in construction	2		2
Installation of wiring within panels in construction	7		7
Ventilation of roof within panels	2		2
Rendering panels insect repellent	3	1	4
Curved panel	1	_	1
TOTAL:	28 (82%)	6 (18%)	34

SOURCE: Field interviews and panel installation manuals (see methods).

The importance of user innovation in this industry is further enhanced by a second related finding: in all cases, users innovated before the manufacturers to accomplish each function listed in Table 2. That is, the manufacturers' innovations were essentially functional substitutes for existing user innovations. For each function, the users had solved the problem and used the solution for several years before the manufacturer introduced an innovation which accomplished the same function.

The predominance of innovation in stressed-skin panels by builders is surprising because, on the face of it, builders would be expected to gain less economic benefit than manufacturers from these innovations: residential builders have a very low market concentration while the concentration of manufacturers of stressed-skin panels is very high (Table 3).

TABLE 3: CONCENTRATION OF MANUFACTURERS OF AND BUILDERS USING STRESSED-SKIN PANELS: 1989

COMPANY TYPE	SHARE OF TOTAL OUTPUT
4 Largest Panel Manufacturers	77%
4 Largest Builders using panels	1%

TOTAL 1989 SALES: 5,000 units

NOTE: Panel sales are converted to equivalent number of residential units using the average enclosed square footage.

SOURCE: Field interviews.

From considerations of appropriability of innovation benefit, one would expect that the manufacturers in the highly concentrated panel manufacturing industry would expect to garner greater benefits from innovations through their market shares than would even the largest builders in the very fragmented panel user industry (Schumpeter, 1942; von Hippel, 1988). With these relative levels of expected benefits and their strong market position, the manufacturers might be predicted to be the major sources of innovations.

Yet this research reveals a different pattern, where the small building companies with insignificant shares of the stressed-skin panel market are the major sources of innovations in the panels. The benefits which the builders receive from these innovations must therefore include other factors than market power alone.

To explain the far greater number of innovations from the users than from the manufacturers, alternative incentives and the mechanisms for appropriating these benefits need to be examined in depth. Three principal causes were identified: (1) the cost of user solutions is low; (2) the cost of delay for users is high and manufacturer solutions delivered to the site would take longer than would the creation of local user solutions; and (3) the cost of regulatory approval is less for users than for manufacturers.

3.1.1: COST OF FINDING SOLUTION

In the sample I studied, I found that all user innovations to stressed-skin panels had important attributes in common. First, they were ad hoc responses to problems encountered in the course of a construction project that an innovating builder was engaged in. They were emphatically not "R&D projects" in any formal sense. The innovations were also very rapidly fabricated and installed at a low cost, using materials and equipment on hand at the job site. Clearly, this picture conforms to the findings of research on problem-solving that concludes that solutions are often sought first from the resources immediately available and from recent experience (Marples, 1961; Allen and Marquis, 1964; Bergen, 1984).

In the instance of the 28 innovations in stressed-skin panels created by users, the time from discovery of the problem to installation of the completed solution on the site was only 1/2 a day on average (Table 4). The total cost of each innovation, of time plus equipment and materials, was very low, averaging only $153. Let me provide an example of a builder innovation, to convey their flavor.

> Example: A novel, builder-developed method for installing a wall switch in a stressed-skin panel
>
> Faced with the immediate problem of installing a wall switch in a stressed-skin panel, a builder devised a means of cutting a hollow in the foam at the center of the panel that would accomodate a switch box and related wiring. His method had the advantage of not cutting the panel facing sheets, and involved melting the foam with a heated wire. This method is now widely used by builders.
>
> The builder-innovator reports that the total time that the innovation took was only an hour, and the total cost for time and material equalled $40.

Table 4 lists the actual elapsed time from perceiving the problem and achieving and installing the solution on-site, as well as the total time and material cost for the builder innovations. The costs for each innovation are averaged within each functional category shown in table 4.

TABLE 4: INNOVATIONS TO STRESSED-SKIN PANELS: AVERAGE COST OF USER INNOVATION INSTALLED ON-SITE BY FUNCTION

FUNCTION	AVERAGE ELAPSED TIME (days)	AVERAGE M+T COSTS	N
Framing of openings within panel	1/10 DAY	$20	1
Structural connect between panels	1/10	30	2
Ventilation of roof within panels	1/10	32	2
Insulated connect between panels	1/10	41	3
Corner connect between panels	1/5	60	1
Installation of HVAC within panels in construction	1/5	60	2
Installation of wiring within panels in construction	1/5	79	7
Connection of panel to roof	1/5	80	1
Rendering panels insect repellent	2/5	123	3
Connection of panel to foundation	1/2	160	1
Connection of panel to frame	1 1/5	377	3
Development of curved panel	5	1,500	1
AVERAGE INNOVATION TIME AND COST FOR ALL FUNCTIONS:	1/2 DAY	$153	(28)

NOTE: Cost of innovation calculated from material and equipment cost plus labor cost valued at $280 per work day.

SOURCE: Field interviews and Means (1989).

3.1.2: COST OF DELAY

Any delay in obtaining solutions to problems can have high costs for a builder, since delays mean that work crews are not completing tasks, and the schedule of deliveries, subcontractors, and other activities must be altered to reflect the changed timetable. Even if a manufacturer learned of the need for an innovation as soon as a user discovered it, and even if the manufacturer's costs and times for developing an innovation were as low as those shown on table 4, above, the manufacturer's off-site location means that a manufacturer could not deliver the innovation to the builder as rapidly as the builder could build it "on the job".

In the case of the stressed-skin panel-related innovations, the average delay for the manufacturers to respond to identified problems is estimated at over 40 work days, which can be valued at $280 a workday in lost costs for the builder. While it is doubtful that a builder would actually delay construction for that long waiting for the manufacturer to solve a problem, the estimation of the costs can provide a basis on how the builders value their alternatives.

Table 5 presents the estimated delay time for the manufacturer to make and deliver a solution to the site. This is a conservative estimate because it excludes any time for innovation problem-solving, considering <u>only</u> the amount of time

required to actually fabricate a product incorporating the innovation and deliver it to the site. [3]

TABLE 5: INNOVATIONS TO STRESSED-SKIN PANELS: AVERAGE COST OF DELAY FOR BUILDER BY FUNCTION

FUNCTION	AVERAGE TIME	AVERAGE DELAY COSTS
Connection of panel to foundation	5 DAYS	$1,400
Framing of openings within panel	5	1,400
Connection of panel to frame	10	2,800
Corner connect between panels	10	2,800
Connection of panel to roof	10	2,800
Installation of wiring within panels in construction	10	2,800
Installation of HVAC within panels in construction	10	2,800
Structural connect between panels	10	2,800
Insulated connect between panels	10	2,800
Development of curved panel	100	28,000
Ventilation of roof within panels	100	28,000
Rendering panels insect repellent	250	70,000
AVERAGE TIME AND DELAY COST FOR ALL FUNCTIONS:	44 DAYS	$12,367

ASSUMPTIONS: 1) Manufacturer willing and able to provide an innovation for each function; 2) minimum response time for manufacturer to solve problem, fabricate panel and deliver to site is five days.

NOTE: Cost of delay to builder calculated at $280 per work day from crew down-time and rescheduling, estimated from industry average of cost per workhour for appropriate crew.

SOURCE: Field interviews and technical manuals; Means, 1989.

As shown in table 5, a delay of at least five days would be necessary for the manufacturers to solve even the easiest problem, fabricate a panel and deliver it to the site (from field interviews). This delay can be valued at the cost to the builder for crew down-time and rescheduling. More complex problems would entail longer delays and thus have greater costs for the builders.

Let me provide two examples, wall switch wiring and ventilation of roof panels, to demonstrate how I calculated the costs of delay shown in table 5.

The delay for a manufacturer to deliver a panel incorporating the innovation (mentioned earlier) enabling the installation of a wall switch in a stressed-skin panel would be at least five days. The cost of delay would include re-scheduling the electricians and interior finish crews whose work depend upon the completion of

this task. The steps the manufacturer would take (from interviews) during this five-day period would be: 1) receive information on switch location; 2) make panel; 3) create hollow for switch; and 4) deliver the panel to site. The cost of the five day delay for the builder has a value of $280 per workday or $1,400.

The second innovation (developed by a builder) involved the reduction of heat in panels used as roofing via the construction of air channels for ventilation. The innovating builder quickly achieved this function on his job site by using appropriately-oriented thin strips of wood (wood strapping) along with properly-located vents. If a manufacturer were to attempt to fabricate a panel containing an innovation of this same function (and this step was eventually taken by some panel manufacturers), it would take an estimated minimum of 100 man-days.

The estimated elapsed time is longer in this instance than in the instance of the wiring innovation mentioned above because more complex design and fabrication stages would be required. A manufacturer would need to complete the following stages: 1) estimate performance criteria; 2) design panels; 3) perform engineering analysis of panel strength, bending, and other specifications; 4) change panel production system; 5) make panel; and 6) deliver the panel to site.

The cost of 100 days delay to the builder are valued at $280 a workday, with a total cost of $28,000. These costs would include crew down-time and rescheduling of carpenters, roofers, and exterior finish crews.

3.1.3: COST OF REGULATORY APPROVAL

The final cause that explains the high incidence of innovation by users relative to manufacturers is that the costs of obtaining regulatory approval are in general lower for the user than for the manufacturer. I have identified two reasons for this.

First, applicable regulations place a far greater burden on the manufacturers who develop and sell innovative products than on the builders who may develop and use such products; the builder either can demonstrate that an innovation meets the specified code or performance requirements, or can provide field test evidence to the satisfaction of the local inspector (Ehrenkrantz Group, 1979; Duke, 1982). In contrast, manufacturers delivering products can be required to provide test data demonstrating code compliance for each locality served (Duke, 1988). Testing new products for compliance in a given locality can take from 1 month to several years, and explicit code approval often takes several additional years (Ehrenkrantz Group, 1979).

Second, the nature of liability is different for builders and manufacturers. In construction, "the contractor does not guarantee a satisfactory result [with respect to a manufacturer's product, but] merely warrants that he will perform the project and install the systems in a workmanlike manner...[In contrast] manufacturers can be found liable [under negligence in] defective design and failure to warn users...the manufacturer warrants that the goods are fit for the particular purpose" (Barnes and Ulin, 1984).

3.2: INNOVATIONS DEVELOPED BY USERS DIFFER SIGNIFICANTLY FROM THOSE DEVELOPED BY MANUFACTURERS

As can be seen in table 6, half of the user innovations concern the connection of the panels to other systems, while none of the manufacturer innovations extend beyond the single component of the panel itself.

TABLE 6: INNOVATIONS IN STRESSED-SKIN PANELS: INNOVATIONS BY TYPE AND SOURCE

TYPE OF INNOVATION	SOURCE OF INNOVATION USER	MFR
Panel-related only	50% (14)	100% (6)
Connection of panel to other house components	50% (14)	0% (0)

SOURCE: Field interviews.

Panel-related innovations are those that concern only the panels themselves, such as their shape, or the connections between the panels. Connection innovations can be explained as follows: in order to use stressed-skin panels in a structure, the panels must be connected to other structural systems, such as the foundation and the framing for the floors and the roof. Panels must also accomodate the services, such as heating and electricity. Innovations that accomplish these functions are coded as "connection" innovation in Table 6.

I argue that builders innovate in the connections of the panels to other components while the manufacturers do not for three reasons: 1) the integration of the components requires specific and timely information; 2) the integration entails specialized applications; and 3) it may significantly extend regions of liability. These three causes reflect the increased complexity inherent in combining different components, and can help explain the absence of manufacturer innovation on connections.

3.2.1: SPECIFIC AND TIMELY INFORMATION

A manufacturer wishing to innovate with respect to the connections among components must obtain information regarding the components' composition and performance requirements. This information may change often and quickly, depending upon the environment and any shifts in operational requirements. The user not only has immediate access to this information, but may also be able to excercise some degree of control over the forces provoking the changes. The manufacturer does not and cannot.

More difficult than both the quantity of detail and the frequency of changes is the fact that much of the information is not specifiable. The reasoning that guides the problem-solving for these connections is not explicit; it often relies upon constant feedback through trial and error, informed by experience and judgement (Polanyi, 1958; Mitroff, 1968; von Hippel, 1990). Because the manufacturer is

separated from the source of this information (that is, the application stage itself), any information that the manufacturer receives must be translated and transmitted, and any information which cannot be specified is thereby lost (Teece, 1981). Continuing attempts to gather or infer this missing information will only increase costs for the manufacturer and increase the possibility of using wrong information; in von Hippel's terms, the information is "sticky" at the user's site (von Hippel, 1990).

The advantage that builders have over manufacturers with respect to this information explains in part why the users, rather than the manufacturers, create innovations which connect separate components. Some researchers hypothesize that the difficulty and cost involved in transmitting this type of information can determine the locus of problem-solving (von Hippel, 1990; Clark, 1989). This hypothesis appears to be confirmed from these results.

3.2.2: SPECIALIZED APPLICATION

Innovations that connect different systems are more specialized in their applications than innovations confined to the panels themselves because the connections must fit the specific configuration of components. The integration of the parts not only concerns the specific region of intersection, but also how the separate parts work together as a unit. Seemingly minor changes in one part can require major complementary changes in other parts and the system overall (Henderson and Clark, 1989).

For the manufacturer, attempting to change a product to meet specialized applications may greatly increase the complexity of their product development. Special interfaces may be required to connect the product to each selected component. Given the variety of other systems which could be connected into the panels, the range of specialized applications is usually too broad for the manufacturer to anticipate.

In contrast, the builder's normal activities involve integrating the various components into a fully functional residential unit, so they are more likely to accomplish this activity with a minimum of disruption of their work routines. In the builders' operations, there are no formal separations between integrative activities and other value-adding activities on the construction site. Recognizing and coping with specialized applications is a common activity for the builders because each construction project is unique to some degree (Tatum, 1986). The various elements which make up the productive capacity of the builders (such as equipment and skills) are eminently adaptable to special connection requirements that arise from the selection of specific components.

3.3.3: EXTENDED LIABILITY

The potential liability for manufacturers who commercialize connection innovations includes not only the manufacturer's own products but also those that are physically connected to these products. That is, the liability is expanded to include an implied warranty of the other system and/or the specific connections. If a manufacturer commercializes innovations that connect systems, it could be interpreted as warranting that the goods (in this case, the product, connection, and all systems connected) are fit for the user's purpose (Barnes and Ulin, 1984). This

expanded liability over systems and installation over which the manufacturer has little control is not attractive to most manufacturers.

The nature of a builder's responsibility does not significantly change with respect to specific connections because the standard activities of the construction firm encompass both the customization of components and the integration of the different parts (Duke, 1988; Ehrenkrantz Group, 1979). The builder has a legal responsibility to construct a habitable dwelling "in a workmanlike manner", which includes obtaining and installing all of the different parts and systems.

Thus, while manufacturers observe a significant increase in the region and scope of their liability with the addition of explicit connection of their product to other components, the builders do not perceive a similar increase in their legal responsibility when they connect disparate building components.

3.3: MANUFACTURERS COMMERCIALIZE ONLY A SMALL PORTION OF USER INNOVATIONS

Out of the 28 user innovations, I discovered that the manufacturers commercialized only 29 percent. Though user innovations constitute over 80 percent of all innovations to the stressed-skin panels, the manufacturers do not commercialize many of these existing solutions to problems.

TABLE 7: INNOVATIONS TO STRESSED-SKIN PANELS: COMMERCIALIZATION OF USER INNOVATIONS BY MANUFACTURERS

USER INNOVATIONS	SHARE OF TOTAL
Commercialized by Manufacturers	29% (8)

SOURCE: Field interviews, and industry technical and management documents.

Manufacturers also limit themselves to only commercializing those innovations that concern the panel alone. Out of the thirty four innovations in the stressed-skin panels, 93 percent of the innovations that the manufacturers commercialized were related to the panels alone. Table 3 presents the innovations commercialized by manufacturers by type of innovation.

TABLE 8: INNOVATIONS IN STRESSED-SKIN PANELS: INNOVATIONS COMMERCIALIZED BY MANUFACTURERS BY TYPE OF INNOVATION

TYPE OF INNOVATION	SHARE OF TOTAL
Panel-related only	93% (13)
Connection of panel to other house components	7% (1)
TOTAL:	100% (14)

SOURCE: Field interviews and technical documents.

The only manufacturer commercialization of a user innovation concerning a function outside the panels is a minor addition that doesn't really change either the basic functions of the panel or its connections to other components. (This exception to the general pattern concerns the modification of panels to ease the installation of electrical wiring.)

I propose that the major cause for the low rate of manufacturer commercialization of user innovations involving connections between panels is that the market for any one such innovation is small relative to the market for within-panel innovations, but that the design cost for both is similar. (These costs may include the obtaining of regulatory approvals.)

My interviews show that manufacturers of stressed-skin panels do perceive only a very small market for the innovations that connect panels to other components. The largest 3 manufacturers (who constitute over 70 percent of the market) regard these as "custom orders", and state that custom panel sales equal less than 5 percent of their total annual sales. [4] They also state that they would be unwilling to change the basic panel they produce in any of its elementary performance characteristics - and virtually all of the connection innovations would require just such modifications.

User innovations that are not commercialized by manufacturers are still produced by users on a regular basis. Typically an individual builder-user will have a portfolio of user techniques, and manufacturer-commercialized ones for functions where these are available, that he chooses among as a function of the particulars associated with a specific construction project. The builders surveyed have used most, if not all, of the innovations in this sample at one time or another, and expect to use them in the future (from field interviews). Maintaining this portfolio can provide the builder with greater flexibility than a single method alone can in meeting specialized requirements and changing specifications.

4.0: Discussion

One of the principal findings of this research is that, for the sample of innovations examined, users innovate far more than manufacturers do. Analysis reveals that the incentives for the users to innovate are more complex than previously understood. Users respond to particular conditions inherent in applying technologies; the high cost of any delay and access to specific and timely information provides special incentives for the users to innovate. User innovation in this field may thus be seen as an efficient market response to needs which arise during the implementation of a technology, rather than a failure on the part of manufacturers to respond to identified needs.

The research I have reported on here has focused on the implementation stage of a technology, and the process of "learning by doing" by the users as an effective means of accomplishing specialized applications. By examining a full set of innovations related to a specific technology originating from both manufacturers and users, we can expand our empirical understanding of this phenomenon and begin to develop a broader theoretical framework to encompass the complex incentives that affect user innovation.

It is interesting to note that we have found a high level of innovation in general and user innovation in particular in the residential construction industry, despite the conventional wisdom that little innovative activity is usually expected from this industry overall. Residential construction has been called "an army of pygmies" and a "headless monster" (Ventre, 1979), and "the industry that capitalism forgot [due to] its chronic incompetence and feudal controls" (Fortune, 1947, in Dowall and Lynch, 1986). Significant barriers to innovation clearly do exist in this industry, especially for users. Most residential construction companies are very small firms, with over 90 percent employing less than 10 people (Quigley, 1982). They are extremely sensitive to the cyclicity of the market and the seasonality of the work, both of which discourage capital investment for technological development and human resource investment for the learning required to efficiently utilize new technologies (Manski, 1973; Quigley, 1982; U.S. Congress Office of Technology Assessment, 1986).

Despite these factors, I have found that users innovate far more than manufacturers do. Previous studies of this industry most often attributed innovations which were identified to manufacturers, suppliers, and R&D laboratories in government and universities (Johnson, 1968; U.S. Congress Office of Technology Assessment, 1987; Quigley, 1982). In contrast, in the sample studied in this research, users created over three quarters of all of the innovations studied; similarly strong patterns have been identified in other industries as well (von Hippel, 1988). The three specific reasons which explain the high rate of innovation by users are the low cost of user solutions, the high cost of delay for builders, and the lower regulatory burden for users than for manufacturers.

In the sample of innovations relating to the stressed-skin panels, the users rapidly innovated, making use of material and equipment at hand to quickly develop and install innovative solutions to problems which appeared while the work was in progress. The solutions were not only adequate to solve the problem, but were effective enough to be adopted as a standard solution by the users. In contrast, if the users had appealed to the manufacturers for the solutions, even if the innovation

time and cost are assumed to be equal for the user and manufacturer, the manufacturers would face a significant delay in producing a product which incorporated the solution and delivering it to the work site. This potential cost of delay is sufficient to encourage the users to innovate for themselves despite the potential costs and barriers.

The cost of delay coupled with the availability of low cost user solutions may be widely applicable in predicting the locus of innovative activity. When the cost of delay is consistently high and low cost solutions are possible, users could be expected to innovate far more than the manufacturers because any delay from problems encountered during the implementation of a technology may have costs far in excess of any actual or potential costs incurred from innovating. In such a condition, the users would be expected to innovate to solve the problem and resume the application of the technology as quickly as possible. This prediction contradicts standard theories concerning the distribution of benefits from innovations, as well as studies of the residential construction industry. The conclusion does help explain the pattern observed in this research of user innovations vastly outnumbering manufacturing innovations.

Manufacturers cannot necessarily share in the benefits that users receive from innovating. The fast response that the users accomplish by innovating themselves is not available to the manufacturer. The value of low cost solutions is much higher to the user than it could be to the manufacturer, who doesn't possess the same set of experiences and materials that render the solution low cost for the user. In addition, when the manufacturer faces a larger potential cost for meeting applicable regulations than the user does even if the innovation is exactly duplicated, the cost of delivering it to local markets is far higher for the manufacturer. Under such conditions, the manufacturer would not be expected to commercialize many of the users' innovations--and indeed, this research found that manufacturers commercialize only a small percentage of all user innovations.

The second principal finding of this research is that users innovate on the connections among components while manufacturers do not. This is the first time that a significant difference between user innovations and manufacturer innovations has been demonstrated. The three principal causes identified that explain this difference between user and manufacturer innovations are the users' access to specific and timely information, their ability to meet specialized applications, and the extended liability that may apply to manufacturers' innovations on connections.

Users innovate on these connections because they possess specific and timely information about the implementation of the technology. The manufacturers, on the other hand, are removed from these application activities and from the source of the information. When they regularly face specialized applications, users would be expected to have standard methods of obtaining and using this vital information. While some types of users accomplish specialized applications as part of their normal routines, the manufacturers are usually organized around product classes, and view changes to accomodate special applications as "custom orders", that is, service outside their standard operations. Information for the "custom orders" is often gathered and used by different people within the manufacturing company than those who are responsible for normal product specification. This division of information and application compounds the problems encountered in collecting the data for the

manufacturer.

It could be said that the integration can't be done without the information, but the information can't be obtained without the integration. In such a case, the user would be predicted to be the sole source of innovations which require this information. This research confirms that prediction, since it found that users are the only source of innovations requiring the specific information required to connect the separate components.

This research reveals patterns of user innovation and differences between user and manufacturer innovations which were previously unexplored. It also identifies causes for these results as a first step in the further exploration of innovation during the implementation stage of a technology. I cannot yet weigh the relative influence of any of the causes, but their explanatory power does expand our consideration of the forces operating on users during innovation.

The major implication of this research is that users can be significant sources of innovation, indicating a "de facto" design partnership among users and manufacturers. Users face conditions that are unique to their position in applying technologies. They have incentives which differ from those of the manufacturers, such as the importance of avoiding delay. They also have an increased capability for innovation during the integration of components through their access to the required information. The asymmetry of the information between the user and the manufacturer can be an essential part of making the design partnership work for both sides. In many situations, not only will the users innovate more than the manufacturers, but they will also produce different innovations which are vital for the application of a technology, such as its use in conjunction with other technologies.

One aspect of this design partnership is the potential to reduce the time required for the cycle of the product through successive design stages. The product development process, and in many cases the product itself, can be modified to take advantage of the users' innovations. These innovations consist of technical changes that are already designed, tested and applied by the users and that can be readily incorporated into the manufacturers' products. The resulting products may not only be available at lower cost to the manufacturer but may also meet the needs of the users more exactly.

A second facet of closer ties between manufacturers and users during product development is the opportunity to improve the connections among disparate components. As components are produced in many different locations around the world, and as production in manufacturing moves towards smaller batches, the specification of the connections among components will become an increasingly critical area requiring the management of technological change. Recognizing the interdependence of the integration of components and the specific information required can reshape the assignment of resources and responsibility essential in accomplishing the production of a whole operational unit. The contribution of user innovations can be significant in this arena, unattainable through any other means.

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1. I chose to conduct field interviews because other sources would not yield appropriate levels or types of information for the theory development. Available industry statistics usually concentrate on the finished characteristics of a residential structure rather than the operations used to construct it. Industry analyses which explicitly consider the inputs for construction do not also address the processes which effect the value of the output. The focus of my research, however, includes an examination of the inputs and production processes evaluated in the light of the value of the final product.

I judged survey questionnaires inappropriate to my objective of theory development. Surveys need to include general questions designed to elicit answers applicable to a wide range of respondants. My own research requires detailed information which is difficult to receive without direct interaction with the respondant. A key aspect for user innovations seems to be the unpredictability of site conditions, a difficult topic to anticipate for a survey.

The identified innovations to the stressed-skin panels were checked for validity and comprehensiveness by asking builders, manufacturers, and experts to review the list and accompanying information. Industry technical and management documents and trade journals, newletters, and other publications provided an additional check on the data, particularly the identification of innovation sources and time of appearance.

The strengths and weaknesses of the sample of innovations to stressed-skin panels reflect the data collection method of in-depth interviews. One of the strengths of this data is that the interviews provided detailed information about each innovation, including the history of its creation, introduction and commercial application as well as functional and operational aspects. Another is that this technique allowed me to identify <u>all</u> user innovations, rather than being confined to those commercialized by manufacturers. It also covers a sufficient time period (from around 1970 to the present) for the interview respondants to accumulate experience with the panels and their installation in habitable dwellings. One of the weaknesses of the data is that in-depth interviewing is time-consuming and resource-consuming, leading to a small sample size. The interviews also produce qualitive information which, together with the small sample size, limits the type and levels of statistical analysis which can be performed on the data.

2. The builders not only innovated extensively in modifying the panel during implementation, but they also were responsible for the original innovation of the panel itself. Though several attempts had been made to introduce plastic foam core stressed-skin panels to residential construction, these commercial ventures all failed (Andrews, 1988). During the early 1970s, builders re-invented the panels by assembling components already in use to function as load bearing units, without any knowledge of previous commercial ventures. The current structure of the panel manufacturing and market reflects its builder origin.

3. This cost of delay does <u>not</u> include any extra costs charged for solving the problem (some firms charge $50 an hour for engineering time), and it does not include customization costs for a special order panel.

4. This figure excludes panels cut to specific sizes, and primarily entails customized location of electrical wiring chases.